

# NUMERICAL METHODS

C / KAPPA EXAM 12 / 11/19 / 2022 / 20.000

## LEAST SQUARES REGRESSION

Goal: minimize the sum of the squares of the residual errors.



$$S_r = \sum_{i=1}^n d_i = \sum_{i=1}^n (y_i - a_0 - a_1 x_i)$$

1. sum of the square errors.  
2. minimize the square of the errors.

$$a_0 = \frac{\sum y_i}{n} \quad a_1 = \frac{\sum x_i y_i}{\sum x_i^2} \Rightarrow a_0 = 5 - 0.8$$

## STANDARD ERROR:

$$S_{y_1} = \sqrt{\frac{\sum y_i^2}{n-2}} \quad S_{y_2} = \sqrt{\frac{\sum (y_i - \hat{y}_i)^2}{n-2}}$$

## STANDARD DEVIATION:

$$S_y = \sqrt{\frac{\sum y_i^2}{n-1}} \quad S_x = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

$$a_0 = 5 - 0.8x$$

## POLYNOMIAL QUADRATIC REGRESSION:



$$S_r = \sum_{i=1}^n (y_i - a_0 - a_1 x_i - a_2 x_i^2)^2$$

Take derivative of  $S_r$  to find the error.

$$\frac{\partial S_r}{\partial a_0} = -2(\sum y_i - \sum a_0 - a_1 \sum x_i - a_2 \sum x_i^2) = 0$$

$$\frac{\partial S_r}{\partial a_1} = -2(\sum y_i x_i - \sum a_0 \sum x_i - a_1 \sum x_i^2 - a_2 \sum x_i^3) = 0$$

$$\frac{\partial S_r}{\partial a_2} = -2(\sum y_i x_i^2 - \sum a_0 \sum x_i^2 - a_1 \sum x_i^3 - a_2 \sum x_i^4) = 0$$

$$\begin{bmatrix} \sum x_i^0 & \sum x_i^1 & \sum x_i^2 \\ \sum x_i^1 & \sum x_i^2 & \sum x_i^3 \\ \sum x_i^2 & \sum x_i^3 & \sum x_i^4 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} \sum y_i \\ \sum y_i x_i \\ \sum y_i x_i^2 \end{bmatrix} \rightarrow [A][X] = [B]$$

## PDE'S

### FINITE DIFFERENCE METHOD:



**PROBLEM 1:**  
 1D Rod problem  
 $L=1, R=0, C=0$   
 $T=0$   
 $u_x = 0$   
 $u = 20^\circ C$   
 - CENTRAL DIFFERENCE  
 $u_{i+1}(t) = \frac{u(t) - \Delta x u_x}{\Delta x} - 2u_i(t) + u(t + \Delta x)$   
 $u_{i-1}(t) = \frac{u(t) - \Delta x u_x}{\Delta x} - 2u_i(t) + u(t - \Delta x)$

## EIGEN VALUES

$\lambda = \text{eigen value}$

**Example:**  
 $\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$

**TRICK:**  
 $\begin{bmatrix} a_{11}-\lambda & a_{12} & a_{13} \\ a_{21} & a_{22}-\lambda & a_{23} \\ a_{31} & a_{32} & a_{33}-\lambda \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$

**Single 2x2:**  
 $A = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$   
 $\Delta(x) = \det \begin{bmatrix} a-\lambda & b \\ c & d-\lambda \end{bmatrix} = 0$   
 $\lambda = \frac{a+d}{2} \pm \sqrt{\left(\frac{a-d}{2}\right)^2 + bc}$

**Two eigen values with same:**  
 $\begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$   
 $1x_1 + 1x_2 = 0 \Rightarrow x_1 = -x_2$   
 $1x_1 + 1x_2 = 0 \Rightarrow x_1 = -x_2$   
 $x_1 = \begin{bmatrix} 1 \\ -1 \end{bmatrix}$

**Two eigen values with different:**  
 $\begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$   
 $-1x_1 + 1x_2 = 0 \Rightarrow x_1 = x_2$   
 $1x_1 + -1x_2 = 0 \Rightarrow x_1 = x_2$   
 $x_1 = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$

**INTERNAL:**  
 $u_{i,j} = \frac{u_{i+1,j} + u_{i-1,j} + u_{i,j+1} + u_{i,j-1}}{4}$

**RIGHT BOUNDARY B.C.:**  
 $\frac{\partial u}{\partial x} = u_x = \frac{u_{i+1,j} - u_{i-1,j}}{2\Delta x}$   
 $u_{i,j} = u_{i-1,j} + 2\Delta x u_x$

**LEFT BOUNDARY B.C.:**  
 $\frac{\partial u}{\partial x} = u_x = \frac{u_{i+1,j} - u_{i-1,j}}{2\Delta x}$   
 $u_{i,j} = u_{i+1,j} - 2\Delta x u_x$

**TOP BOUNDARY B.C.:**  
 $\frac{\partial u}{\partial y} = u_y = \frac{u_{i,j+1} - u_{i,j-1}}{2\Delta y}$   
 $u_{i,j} = u_{i,j+1} + 2\Delta y u_y$

**LEFT BOUNDARY B.C.:**  
 $u_{i,j} = u_{i-1,j} - 2\Delta x u_x$

## INTERPOLATION

Use a 4th order polynomial

Order	Nodes	Degree	Nodes
1st	2	1	2
2nd	3	2	3
3rd	4	3	4
4th	5	4	5

$P_n(x) = a_0 + a_1 x + a_2 x^2 + \dots + a_n x^n$

**ORDER:**  
 $n=1$  (line)  
 $n=2$  (parabola)  
 $n=3$  (cubic)  
 $n=4$  (quartic)

**TURN:**  
 $n=1$  (0)  
 $n=2$  (1)  
 $n=3$  (2)  
 $n=4$  (3)

**SPINES:**  
 $P_n = \frac{f(x_{i+1}) - f(x_i)}{x_{i+1} - x_i}$

## ODE'S

**Runge-Kutta Method:**  
 $y_{i+1} = y_i + f(x_i, y_i) \Delta x$   
 $\frac{dy}{dx} = f(x, y)$

**Heun's Method:**  
 $y_{i+1} = y_i + f(x_i, y_i) \Delta x$   
 $\frac{dy}{dx} = f(x, y)$

**Taylor Series:**  
 $y(x+\Delta x) = y(x) + \Delta x \frac{dy}{dx} + \frac{\Delta x^2}{2} \frac{d^2y}{dx^2} + \dots$   
 $y(x-\Delta x) = y(x) - \Delta x \frac{dy}{dx} + \frac{\Delta x^2}{2} \frac{d^2y}{dx^2} - \dots$

## CLASSIC 4th ORDER RUNGE-KUTTA:

$y_{i+1} = y_i + \frac{\Delta x}{4} (k_1 + 2k_2 + 2k_3 + k_4)$   
 $k_1 = f(x_i, y_i)$   
 $k_2 = f(x_i + \frac{1}{2}\Delta x, y_i + \frac{1}{2}k_1 \Delta x)$   
 $k_3 = f(x_i + \frac{1}{2}\Delta x, y_i + \frac{1}{2}k_2 \Delta x)$   
 $k_4 = f(x_i + \Delta x, y_i + k_3 \Delta x)$

**Forward Time, Space-Center:**  
 $y_{i+1} = y_i + \Delta x \sum_{j=1}^n B_j k_j$  (Lax-Wendroff)

**Backward Time, Space-Center:**  
 $y_{i+1} = y_i + \Delta x \sum_{j=1}^n C_j k_j$  (Lax-Wendroff)

**[A] MATRIX:**  
 $u_{i,j+1} = 4u_{i,j} - u_{i,j-1} - u_{i,j+1} - u_{i,j-1} = -2\Delta x u_x$   
 $-2u_{i,j+1} + 4u_{i,j} - u_{i,j-1} - u_{i,j+1} - u_{i,j-1} = -2\Delta x u_x$   
 $-2u_{i,j+1} + 4u_{i,j} - u_{i,j-1} - u_{i,j+1} - u_{i,j-1} = -2\Delta x u_x$   
 $-u_{i,j+1} - u_{i,j-1} + 4u_{i,j} - 2u_{i,j+1} - 2u_{i,j-1} = -2\Delta x u_x$   
**TOP:**  
 $-u_{i,j+1} - u_{i,j-1} + 4u_{i,j} - 2u_{i,j+1} - 2u_{i,j-1} = -2\Delta x u_x$

**5th ORDER:**  
 CENTERED FINITE-DIFFERENCE DERIVATIVE  
 $f'(x) = \frac{f(x) - f(x-h)}{h}$   
 $f'(x) = \frac{f(x-h) - 8f(x) + 8f(x+h) - f(x+h)}{12h}$

# Numerical Analysis Using R

**L Towne**



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